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GROUND CALIBRATION OF A STRAIN-GAUGED CT-4A AIRCRAFT (1979),(U)
APR 81 R P CAREY, S P COSTOLLOE
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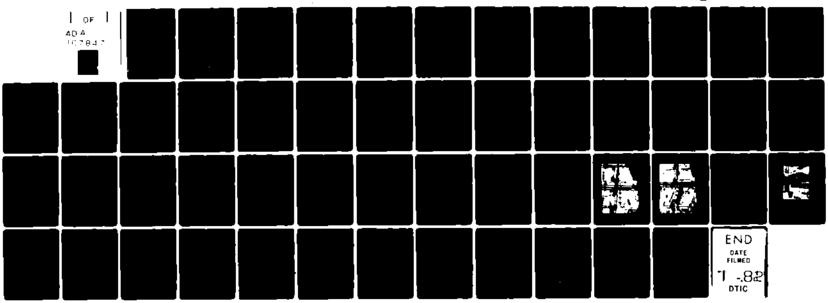

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R.P. CAREY and S.P. COSTOLLOE

SUMMARY

A strain-gauged CT-4A aircraft was calibrated for external loadings as a supplement to flight testing. The loading has been described and the outputs from regression analyses on the strain/load data have been tabulated.

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16. ABSTRACT:

A strain gauged CT-4A aircraft was calibrated for external loadings as a supplement to flight testing. The loading has been described and the outputs from regression analyses on the strain/load data have been tabulated.

CONTENTS

1. INTRODUCTION

The "Airtrainer", CT-4A, is a small twin seater aircraft built by New Zealand Aerospace Limited and used by the RAAF for initial flying training. It is a low wing all metal aircraft with a non-retractable tricycle landing gear.

A.R.L. is involved in determination of flight loads in preparation for fatigue testing. The method being used involves in-flight measurement of airframe strains coupled with ground calibration to determine strain/load relationships. At the time of preparing this memo, ground calibrations had been performed twice (March 1977 and September 1979).

The ground calibration method is described herein and results obtained in 1979 are presented. Loading cases treated in the body of the report are wing bending, tailplane, fin, control stick, and flap bellcrank. Wing torque loadings are treated briefly in Appendix I. Calibration of the main undercarriage is covered elsewhere (Reference 1).

2. AIRCRAFT STATUS

The flight test aircraft, designated A19-031, was transferred to A.R.L. from Aircraft Research and Development Unit in South Australia for the two series of ground calibrations performed in 1977 and 1979.

Items removed from the aircraft for the duration of both calibrations included the cockpit canopy, nose undercarriage, rudder, and elevator. Main undercarriages were removed for the 1977 calibration but left on for the later calibration.

Electric resistance strain gauges were applied to the airframe at 40 positions as shown in Fig. 1. Further details of gauge locations are given in ARL Drawings 53428, 53429, 53431, 53432 (wing gauges), Drawing 53433 (fuselage, control stick, and flap actuator gauges), and Drawing 53430 (tailplane and fin).

Most of the gauges were applied in New Zealand during airframe manufacture in 1974.

3. LOADING METHODS

3.1 Wing Bending Case

The wing bending calibration is illustrated in Fig. 2 (diagramatic) and in Figs. 3 and 4 (pictorial).

Upwards loading was applied hydraulically with a single floating jack that loaded two whiffletrees - one on each half of the wing. Six timber contour boards transmitted the load into each half-wing at alternate ribs. The above loading was applied in the transverse vertical plane containing the wing main spar datum (fuselage station 2299 mm) and the resultants on each side were inclined inwards by the amount of the wing dihedral (6°45'). The hydraulic loading system was the only means of applying load increments during the calibration.

For reasons listed in Appendix II, dead weights, totalling about 560 kg. per side and constant, were hung from the contour boards at the wing leading edge and the 60% local wing chord position.

The loading was reacted by restraining the fuselage at two locations - through a dummy nose undercarriage (station 1120 mm approximately) and through the stiffened floor behind the pilots seat, station 3440 mm approximately. The same support points were used for all other cases.

The pitchwise alignment of the aircraft was such that the fuselage reference line was horizontal. (This follows a fuselage longeron 160 mm below the sill of the cockpit).

Distributions of wing bending moment and shear force resulting from a 1 g load increment are shown in Fig. 5. Both theoretical and nominal calibration distributions are given.

The bases for determining wing loads are treated briefly in Appendix II.

3.2 Tailplane

The tailplane calibration system is shown in Figs. 6 and 7. The dead weight loading, either upwards or downwards, was shared between port and starboard elevator pivot points. Upward loads were monitored by a strain gauged load link in 1977 but a pair of spring balances were used in 1979.

3.3 Fin

The simple dead weight loading system for the fin is illustrated in Fig. 8. It utilized cables, pulleys and a small strain-gauged load measuring link.

3.4 Control Stick

The control stick was loaded by a turnbuckle in a linkage attached to the hand grip 0.38 metres above the upper pivot as shown in Fig. 9 (and 0.46 metres above the lower pivot).

To react the load on the control system, the elevator control rod was restrained at the rear of the aircraft.

3.5 Flap Bellcranks

The flap bellcranks are located on the sides of the fuselage and are part of the flap actuating linkage. The flaps were disconnected and the bellcranks were rotated to a starting position such that deflection under load left the port bellcrank just clear of its stop.

Turnbuckles and an overhead crane were used to load port and starboard bellcranks simultaneously as shown in Fig. 10.

4. CALIBRATION LOADINGS

A list of the calibrations performed in 1979 is given in Table 4.

The wing bending calibrations started at -1 g load factor and went through to +3 g in a continuous loading sequence.

The tailplane and the fin were loaded in opposite directions without changing the strain gauge zero settings. This was intended to take account of slipping or other discontinuous behaviour of the structure as the load direction was reversed.

All calibrations were preceded by two full scale preliminary loadings to settle the structure down.

5. DATA TREATMENT

5.1 Data Collection

During the 1979 calibrations data from strain gauges were processed by a Doric Model 210 portable data-logger and a Facit tape-punch, model 4070, whose output was suitable for computerised analysis. Printout on paper was also obtained from the "Doric" for "quick look" and duplicate purposes.

The Doric and Facit equipment replaced a Leach MTR 2900 flight recorder used in 1977 but unavailable in 1979.

5.2 Data Processing

Linear regressions against load were fitted for the output of each strain gauge.

The regressions for the wing bending calibrations covered the whole range from "-1 g" to "+3 g", firstly on a run by run basis, and then pairing runs performed on the same day. A zero load (zero Newton) strain datum for this case was derived by interpolation between the first available adjacent data points, as strains were not measured at zero load.

Tailplane analyses treated separately the loadings in upward and downward directions and then combined all loadings. Fin analyses first treated loadings to port and starboard separately and then combined them.

5.3 Sign Conventions

The sign convention for loading was such that upwards, forwards, and starboard loads were positive.

The relationship between the signs of strain bridge outputs and the sense of structural distortion is not readily available except in the obvious cases such as the bending bridges on the wing main spar. In strain computations the following form has been consistently used:-

$$\text{Strain} = (\text{Reading at load} - \text{Reference value}) \times \frac{\text{Strain Equivalent} (+\text{ve})}{\text{Calibration Step} (-\text{ve})}$$

6. RESULTS

6.1 Results of 1979 Calibrations

Regression line gradients are given in Tables 5 to 7 (wing bending), Table 8 (tailplane), Table 9 (fin), Table 10 (control stick), and Table 11 (flap levers).

Strain intercepts at zero load are given in Tables 12 to 14 (wing bending), Table 15 (tailplane), Table 16 (fin), Table 10 (control stick), and Table 11 (flap levers).

Plots of strain versus load for strain gauges of particular interest are given in Figs. 11 to 25.

6.2 Comparison - 1977 and 1979 Results

A similar calibration of the same aircraft was done in 1977, and Tables 17 to 21 compare the strain gradients found then for wing, tailplane, and fin with the 1979 values. Also shown is the difference or change between the strains induced by the full range of the calibration load for each gauge.

7. DISCUSSION OF RESULTS

7.1 Wing Loadings

1. The important gauge station 12BE on the main spar centre section gave a particularly large (14%) change in response between 1977 and 1979. An investigation showed that response from one arm of the bridge was very low - a firm indication of debonding.

2. Out of 20 gauges recorded during wing bending calibration, seven had changes above 5% from 1977 to 1979. It is considered that this is an indication of the inherent variability of the load paths through the structure.

3. There is a surprisingly high ratio (approximately 2) between the responses of 21SE and 22SE which are similarly placed front spar shear bridges (see Table 7 and Figs. 19 and 20). It may be worth noting that the R.A.A.F. have introduced modifications, STI121 and STI124, in the region of the front spar inboard. These modifications replace and improve the fit of the front spar web panel where 21SE and 22SE are placed. Access is also provided to facilitate tightening of bolts holding a wing bracket forming part of the wing/fuselage front attachment.

4. The response of gauge 32RA, the spanwise arm of a skin rosette, is only about one third of the output from 9BE and 10BE on the main spar, similarly oriented to 32RA and further outboard. (Figs. 12 and 21). It is likely that skin buckling greatly modified the response of 32RA.

5. Gauge 18CE on the upper cap of the rear spar gives a very small output compared with 20TE on the lower cap. (Figures 13 and 14). This is at least partially attributable to additional load carrying material on the top side of the spar.

6. The root rib bending gauges, 27BE and 28BE, on opposite sides of the aircraft, differ by 22%, with the starboard side having the greater slope. This appears to be further indication of the variability of load transfer.

7.2 <u>Tailplane Loadings</u>

1. The response of tailplane gauges was variable in respect to

(a) difference of slope between port and starboard positions:- 7%,

(b) difference of slope between upwards and downwards loading:- 3 to 5% (also noted in Reference 2),

(c) difference of slope between 1977 and 1979:- 6 to 9%.

2. The responses of tailplane gauges 37BE and 38BE exhibited a waviness of the order of 20 microstrain departure from linearity (5% of peak strain). Qualitatively this would be consistent with buckling of the tailplane skin observed during calibrations. (see Fig. 25).

3. Separate regression lines for upward and downward loadings show a displacement of 10 to 20 microstrain (2 to 5% of peak strain) between the intersections on the strain axis (Table 15 and Fig. 25). (The same strain origins were used for both directions of loading).

4. The response of the fuselage longeron gauges is rather low and two of the four (51CE and 54TE) vary significantly between 1977 and 1979 (Table 20).

5. It should be noted that the tailplane gauges were damaged and replaced shortly after the 1979 ground calibrations.

7.3 Fin Loadings

1. The response of fin gauges varied as follows:-

(a) difference of slope between port and starboard gauge locations:-4%,

(b) difference of slope between port and starboard loading directions:-1.5 to 6%, (gauges show consistently higher slope in compression as noted in Reference 2),

(c) difference of slope between 1977 and 1979 calibrations:-4 to 5%,

(d) hysteresis between loading and unloading:- approximately 20 microstrain, (6% of peak strain).

2. Separate regression analyses for port and starboard loadings indicate a displacement of 30 to 50 microstrain between the intersections of the regression lines with the strain axis (strain datum fixed throughout). The 50 microstrain value represents approximately 14% of the peak calibration strain. (See Fig. 24). This may be an indication of stick/slip behaviour at low loads.

3. The response of fuselage longeron gauges is small and generally variable between 1977 and 1979. The change of sign of longeron gauges 53TE and 54TE is rather surprising, especially since these gauges exhibit consistent (like) sign during tailplane calibrations (Table 20). Also the magnitudes of responses on fin calibrations are roughly similar in spite of the sign changes.

4. It is noted (Table 9) that the slopes obtained from all-in regressions combining starboard and port loadings do not lie between the regression slopes for starboard direction only and port direction only. It is considered that the anomaly is caused

by the offset at zero load between the two regressions. It would be a matter for judgement whether to utilize the slope from the all-in regression, or to take a mean of the separate regression slopes.

8. <u>CONCLUSIONS</u>

1. A particularly large change of output occurred at the important station, 12BE, on the wing main spar centre section. The change of -14% between 1977 and 1979 is believed to be caused by partial debonding of one arm of the bridge. Station 12BE is important because the strains in that area are the highest encountered during the ground calibrations and because the centre section structure is regarded as being fatigue critical and therefore must be investigated.

2. There are a large proportion of gauges involved in the wing bending case whose outputs fluctuate considerably (in excess of 5%) between 1977 and 1979 calibrations.

3. Large differences are noted between mirror image gauge positions (on opposite sides of the airframe) on the wing front spar webs and on the wing root ribs. Also, on the tailplane and fin, there are differences of around 5% between mirror image positions.

4. Looking further at the fin and tailplane results, there are differences in response of the order of 5% when the loading direction is reversed.

5. The fin gauges, 33TE and 34TE, exhibit a large offset (around 14% of peak strain) between regression lines for opposite loading directions. This should be considered when utilizing the results.

6. Outputs from the longeron gauges (51CE, 52CE, 53TE, 54TE) during fin loading are so small and erratic as to be quite unreliable. The gauge 16CE on the wing rear spar is also considered unreliable on similar grounds.

7. The overall indication from the calibrations is that the load transfer through the structure is inherently variable and that the structure consequently does not calibrate with good repeatability.

9. <u>ACKNOWLEDGEMENTS</u>

It is gratefully acknowledged that the 1979 calibrations utilized calibration procedures and load information developed for earlier calibration work by Squadron Leader J. Burt (R.A.A.F.)

The contribution by staff from Government Aircraft Factories in building much of the calibration rig and assisting with the loading is appreciated.

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2. M.G.J. Higgs. Analysis of Ground Calibration Data from Strain Gauges Attached to the Airframe of CT-4A Airtrainer A19-031. A.R.L. Structures Technical Memorandum 296, August 1979.

3. A. Pope. Basic Wing and Aerofoil Theory. McGraw-Hill Book Company, Inc. 1951.

APPENDIX I

WING TORQUE CASES

During the 1977 calibrations two wing torque cases were adopted - a nose up torque and a nose down torque. Both cases started with "1 g" wing bending loading and the torques were applied by adding dead weights to either front or rear weight hangers. The additional loading was counterbalanced by increasing the jack loading through the whiffletree at the main spar line. Details of the additional loads are given in Table 1.

However, the distribution of dead weight differed from the counterbalancing load system applied by the whiffletree. The resulting discrepancy in calibration needed special attention described in Reference 2.

APPENDIX II

DETERMINATION OF LOADS FOR WING BENDING CALIBRATION

1. Aircraft Weight

Data is drawn from the Draft CT-4A Flight Manual (AAP 7212.005-1P) which was issued in December 1974 and was superseded in 1976.

Maximum Permitted Aircraft Mass = 1089 kg.
Half Fuel (200 l. capacity) = 71.8 kg.

Expected Mean Flying Mass = 1017.2 kg.

For calibration the aircraft mass has been taken as 1020.6 kg. (2250 lb.). The corresponding aircraft weight is 10009 N.

2. Full-Span Wing Lift

Wing Lift, L, = nW + LT where n = load factor, W = weight, LT = tailplane lift. If LT is taken as zero, a representative value then:-

Typical Full-Span Wing Lift per g = Weight (W)
= 10009 N.

3. Wing Inertia

(Data from N.Z. Aerospace Ltd. Report CT4-4 page 9)
Wing Mass/Side = 89.36 kg.
Half Fuel Mass/Side = 35.92 kg.
Wing + ½ Fuel Mass = 125.3 kg/side
or
Wing + ½ Fuel Inertia = 1228 N per g per side.

4. Wing Lift Distribution

It was assumed that the distributed lift was an average of two forms - one elliptic and the other proportional to the wing chord. Equal contributions to full span lift were made by the two forms. (This follows the Schrenk method described in Reference 3). When the lift was distributed in that fashion, the aerodynamic lift outboard of the wing root amounted to 4150 N per side.

5. Wing Root Shear Force

Aerodynamic Lift = 4150 N/g/side
Wing & Fuel Inertia = -1228 N/g/side
Root Rib Shear Force = 2922 N/g/side.

6. Effect of Wing Twist on Lift Distribution

A lift distribution representing the effect of wing twist was superimposed on the previously described load factor-dependent lift. The nett effect on the wing outboard of the fuselage was a downwards lift of 316 N per side, independent of load factor. This lift was termed "zero g" lift.

7. Actual Calibration Loading

The actual calibration loading as illustrated in Fig. 2 was a balance of upwards hydraulic loading and constant downwards dead weight loading.

The dead weights fulfilled the following functions:-

(a) Balancing the whiffletree/contour board combination so that the centre of gravity coincided with the input loading line.

(b) Counteracting the weight of the test wing (by reducing dead weights).

(c) Reproducing the lift distribution resulting from the twist of the wing, and

(d) Applying "-1 g" nett loading.

The added dead weights are listed in Table 2, and Table 3 summarises the weights of the wing, whiffletrees, contour-boards and added dead weights. The total weights per side were approximately 8150 N (Table 3), and an opposing jack force of 4920 N per side was exerted, the resultant being a nett "-1 g" loading at the commencement of the calibration.

TABLE 1. WING TORQUE CALIBRATION LOADS

CASE	LOAD LOCATION	ADDED LOADING PER SIDE		
		MASS (KG)	LOAD (N)	METHOD
NOSE UP TORQUE	RIB3 (60% CHORD)	181.4	1778	DEAD WEIGHT
	RIB5 (" ")	34.0	333	" "
	RIB9 (" ")	11.3	111	" "
	WHIFFLETREE ALONG MAIN SPAR		2223	HYD. JACK
NOSE DOWN TORQUE	RIB3 (0% CHORD)	56.7	556	DEAD WEIGHT
	RIB5 (" ")	45.4	445	" "
	RIB7 (" ")	45.4	445	" "
	RIB9 (" ")	45.4	445	" "
	RIB11(" ")	56.7	556	" "
	RIB13(" ")	56.7	556	" "
	WHIFFLETREE ALONG MAIN SPAR		3001	HYD. JACK

NOTE:- These nominal loadings, divided into five equal steps, were additional to a "1 g" loading applied as in the wing bending case.

TABLE 2. DEAD WEIGHTS HUNG ON WINGS (WING BENDING CASE)

RIB NO.	DEAD WEIGHTS HUNG UNDER WINGS (KG)			
	PORT WING		STARBOARD WING	
	LEADING EDGE	60% CHORD	LEADING EDGE	60% CHORD
3	11.3	2.3	9.1	0
5	40.8	20.4	40.8	24.9
7	77.1	59.0	77.1	59.0
9	70.3	56.7	70.3	56.7
11	65.8	52.2	65.8	54.4
13	65.8	54.4	68.0	56.7
TOTAL	576		583	

NOTE:- Marginal differences between port and starboard occur because the whiffletrees were balanced independently.

TABLE 3. CONSTANT LOADS ON WINGS (WING BENDING CASE)

SOURCE OF LOAD	LOAD ON WINGS			
	PORT		STARBOARD	
	MASS (KG)	WEIGHT (N)	MASS (KG)	WEIGHT (N)
WING (WITHOUT FUEL)	91	890	91	890
RIG (CONTOUR BOARDS) ETC.	169	1660	155	1520
DEAD WEIGHTS HUNG ON WING	576	5640	583	5710
TOTAL	836	8190	828	8110

TABLE 4. CT-4A 1979 CALIBRATION LOADINGS

TYPE OF CALIBRATION	TEST DATE	LOAD RANGE (NOMINAL)	NO OF SETS	STEPS	REMARKS
WING BENDING	5 SEPT	-3240 TO +8455 N PER SIDE	2	0.25 g	-1 g TO +3 g LOAD FACTOR
"	13 SEPT	"	2	0.5 g	"
TAILPLANE DOWN LOAD UP LOAD	 10 SEPT	 0 TO 556 N PER SIDE	 2 2	 111.2 N "	STRAIN ZERO. SETTINGS UNCHANGED THROUGHOUT
FIN STARBOARD LOAD PORT LOAD	 10 SEPT "	 0 TO 445 N "	 2 2	 89 N "	STRAIN ZERO SETTINGS UNCHANGED THROUGHOUT
CONTROL STICK	5 SEPT	0 TO 445 N	2	89 N	
FLAP BELLCRANKS	20 SEPT	0 TO 890 N PER SIDE	2	178 N	

TABLE 5. WING BENDING CALIBRATION
STRAIN/LOAD GRADIENTS
TEST DATES: 5 & 13 SEPT. 1979
MAIN SPAR GAUGES

GAUGE NO.	GAUGE LOCATION; DISTANCE FROM AIRCRAFT CENTRELINE	SLOPE: STRAIN ($\times 10^{-6}$) PER LOAD (N) PER SIDE			
		TEST ON 5 SEPT. 1979		TESTS ON 13 SEPT. 1979	
		RUN 1 RUN 2	RUNS (1+2)*	RUN 3 RUN 4	RUNS (3+4)*
12BE	MAIN SPAR; 360 mm STARBOARD	0.0874 0.0877	0.0876	0.0873 0.0877	0.0876
10BE	MAIN SPAR; 1060 mm STARBOARD	0.0743 0.0743	0.0743	0.0745 0.0738	0.0742
9BE	MAIN SPAR; 1060 mm TO PORT	0.0755 0.0757	0.0756	0.0754 0.0750	0.0752
6BE	MAIN SPAR; 1820 mm TO STARBOARD	0.0608 0.0608	0.0608	0.0611 0.0605	0.0608
5BE	MAIN SPAR; 1820 mm TO PORT	0.0630 0.0630	0.0630	0.0628 0.0622	0.0626
2BE	MAIN SPAR; 2830 mm TO STARBOARD	0.0227 0.0227	0.0227	0.0229 0.0228	0.0229

MAXIMUM NOMINAL LOADS -3240 TO +8455 N PER SIDE (UP LOADS +VE)

* COMBINED DATA FROM TWO PREVIOUS RUNS

TABLE 6. WING BENDING CALIBRATION
STRAIN/LOAD GRADIENTS
TEST DATES: 5 & 13 SEPT. 1979
REAR SPAR GAUGES & SKIN ROSETTE

GAUGE NO.	GAUGE LOCATION; DISTANCE FROM AIRCRAFT CENTRELINE	SLOPE: STRAIN ($x10^{-6}$) PER LOAD (N) PER SIDE			
		TEST ON 5 SEPT. 1979		TEST ON 13 SEPT. 1979	
		RUN 1 RUN 2	RUNS (1+2)	RUN 3 RUN 4	RUNS (3+4)
18CE	REAR SPAR; 1060 mm TO STARBOARD	-0.0033 -0.0033	-0.0033	-0.030 -0.031	-0.031
20TE	REAR SPAR; 1060 mm TO STARBOARD	0.0348 0.0349	0.0348	0.0348 0.0348	0.0348
8BE	REAR SPAR; 1820 mm TO STARBOARD	0.0419 0.0419	0.0419	0.0419 0.0416	0.0418
4BE	REAR SPAR; 2830 mm TO STARBOARD	0.0203 0.0202	0.0203	0.0205 0.0204	0.0205
32RA	SKIN ROSETTE; 630 mm TO STARBOARD	0.0241 0.0241	0.0241	0.0243 0.0244	0.0244
32RB	SKIN ROSETTE; 630 mm TO STARBOARD	0.0302 0.0301	0.0302	0.0302 0.0302	0.0302
32RC	SKIN ROSETTE; 630 mm TO STARBOARD	-0.0289 -0.0289	-0.0289	-0.0287 -0.0287	-0.0287

MAXIMUM NOMINAL LOADS -3240 TO 8455 N PER SIDE (UP LOADS +VE)

TABLE 7. WING BENDING CALIBRATION
STRAIN/LOAD GRADIENTS
TEST DATES: 5 & 13 SEPT. 1979
SHEAR GAUGES & ROOT RIB GAUGES

GAUGE NO.	GAUGE LOCATION; DISTANCE AFT OF FUSELAGE DATUM OR SPANWISE	SLOPE: STRAIN ($X10^{-6}$) PER LOAD (N) PER SIDE			
		TEST ON 5 SEPT. 1979		TEST ON 13 SEPT. 1979	
		RUN 1 RUN 2	RUNS (1+2)	RUN 3 RUN 4	RUNS (3+4)
21SE	WING FRONT SPAR SHEAR; 660 mm TO PORT	-0.0103 -0.0104	-0.0104	-0.0103 -0.0103	-0.0103
22SE	WING FRONT SPAR SHEAR; 660 mm TO STARBOARD	-0.0204 -0.0204	-0.0204	-0.0203 -0.0203	-0.0203
26SE	WING ROOT RIB SHEAR; 1800 mm AFT OF FUSE DATUM, STBD. SIDE	-0.0336 -0.0336	-0.0336	-0.0338 -0.0336	-0.0337
30SE	WING ROOT RIB SHEAR; 2840 mm AFT OF FUSE DATUM, STBD. SIDE	-0.0290 -0.0288	-0.0289	-0.0285 -0.0283	-0.0284
24SE	WING REAR SPAR SHEAR; 610 mm TO STARBOARD	0.0116 0.0116	0.0116	0.0113 0.0114	0.0114
27BE	PORT ROOT RIB BENDING; 2360 mm AFT OF FUSE DATUM	-0.0238 -0.0240	-0.0239	-0.0237 -0.0233	-0.0235
28BE	STBD. ROOT RIB BENDING; 2360 mm AFT OF FUSE DATUM	-0.0288 -0.0288	-0.0288	-0.0291 -0.0286	-0.0289

MAXIMUM NOMINAL LOADS - 3240 TO 8455 N PER SIDE (UP LOADS +VE)

TABLE 8. TAILPLANE CALIBRATION LOADING
STRAIN/LOAD GRADIENTS
TEST DATE: 10 SEPT. 1979

GAUGE NO.	GAUGE LOCATION; DISTANCE AFT OF FUSELAGE DATUM OR SPANWISE FROM AIRCRAFT CENTRELINE	SLOPE: STRAIN ($\times 10^{-6}$) PER LOAD (N) PER SIDE				
		UP LOADING		DOWN LOADING		ALL UP & DOWN LOADINGS COMBINED
		RUN 1 RUN 2	RUNS (1+2)	RUN 1 RUN 2	RUNS (1+2)	
36BE	TAILPLANE SPAR 900 mm TO STBD.	0.458 0.454	0.460	0.522 0.520	0.524	0.469
37BE	TAILPLANE SPAR 200 mm TO PORT	0.707 0.701	0.710	0.673 0.671	0.678	0.664
38BE	TAILPLANE SPAR 200 mm TO STBD.	0.726 0.728	0.737	0.708 0.708	0.712	0.708
51CE	FUSELAGE LOWER PORT, 3110 mm AFT	0.080 0.079	0.080	0.089 0.089	0.089	0.089
52CE	FUSELAGE LOWER STBD. 3110 mm AFT	0.097 0.101	0.099	0.108 0.108	0.108	0.108
53TE	FUSELAGE UPPER PORT, 3330 mm AFT	-0.155 -0.153	-0.154	-0.154 -0.153	-0.154	-0.157
54TE	FUSELAGE UPPER STBD. 3330 mm AFT	-0.144 -0.137	-0.143	-0.142 -0.141	-0.141	-0.144

NOTES: 1. MAX LOADS APPLIED = ±556 N PER SIDE (UPWARDS & DOWNWARDS)

2. BE = BENDING; CE = COMPRESSION
TE = TENSION; SE = SHEAR

TABLE 9. FIN CALIBRATION LOADING
STRAIN/LOAD GRADIENTS
TEST DATE: 10 SEPT. 1979

GAUGE NO.	GAUGE LOCATION; DISTANCE ABOVE FUSELAGE REF. LINE (F.R.L.) OR DISTANCE AFT OF FUSELAGE DATUM (F.D)	SLOPE: STRAIN ($X10^{-6}$) PER LOAD (N) PER SIDE				
		LOADING TO STBD.		LOADING TO PORT		ALL STBD. AND PORT LOADINGS COMBINED
		RUN 1 RUN 2	RUNS (1+2)	RUN 1 RUN 2	RUNS (1+2)	
33TE	FIN SPAR, PORT SIDE 190 mm ABOVE F.R.L.	0.717 0.714	0.717	0.763 0.759	0.762	0.787
34TE	FIN SPAR, STBD. SIDE 190 mm ABOVE F.R.L.	-0.748 -0.740	-0.744	-0.735 -0.731	-0.733	-0.820
51CE	FUSELAGE LOWER PORT, 3110 mm AFT	0.042 0.042	0.042	0.040 0.041	0.041	0.040
52CE	FUSELAGE LOWER STBD., 3110 mm AFT	-0.047 -0.047	-0.048	-0.050 -0.050	-0.050	-0.048
53TE	FUSELAGE UPPER PORT, 3330 mm AFT	0.015 0.015	0.015	0.018 0.017	0.017	0.018
54TE	FUSELAGE UPPER STBD., 3330 mm AFT	-0.021 -0.021	-0.021	-0.020 -0.019	-0.019	-0.021

NOTE: MAXIMUM LOADS APPLIED = ±445 N
(TO STBD +VE)
(TO PORT -VE)

TABLE 10. CONTROL STICK CALIRBATION

STRAIN/LOAD GRADIENT & ZERO LOAD INTERCEPT
TEST DATE: 5 SEPT. 1979

GAUGE NO.	GAUGE LOCATION	STRAIN ($X10^{-6}$) PER LOAD N*		STRAIN INTERCEPT AT ZERO LOAD ($X10^{-6}$)	
		RUN 1 RUN 2	RUNS 1 & 2	RUN 1 RUN 2	RUNS 1 & 2
55BE	BASE OF CONTROL STICK.	-2.82 -2.85	-2.84	-5.3 -1.3	-3.3

* positive load - pulling aft on stick.

TABLE 11. FLAP LEVER CALIBRATION

STRAIN/LOAD GRADIENT & ZERO LOAD INTERCEPT
TEST DATE: 20 SEPT. 1979

GAUGE NO.	GAUGE LOCATION	STRAIN ($X10^{-6}$) PER LOAD N		STRAIN INTERCEPT AT ZERO LOAD ($X10^{-6}$)	
		RUN 1 RUN 2	RUNS 1 & 2	RUN 1 RUN 2	RUNS 1 & 2
57BE	PORT FLAP LEVER	0.101 0.103	0.102	-1.8 -2.0	-2.3
58BE	STARBOARD FLAP LEVER	0.098 0.099	0.099	-0.6 -0.9	-0.9

TABLE 12. WING BENDING CALIBRATION
INTERCEPTS OF REGRESSION LINES ON STRAIN AXIS
TEST DATES: 5 & 13 SEPT. 1979
MAIN SPAR GAUGES

GAUGE NO.	GAUGE LOCATIONS; DISTANCE FROM AIRCRAFT CENTRELINE	*INTERCEPTS ON STRAIN AXIS ($X10^{-6}$)	
		TESTS ON 5 SEPT. 1979 (2 RUNS COMBINED)	TESTS ON 13 SEPT. 1979 (2 RUNS COMBINED)
12BE	MAIN SPAR; 360 mm TO STARBOARD	-1.4	-3.3
10BE	MAIN SPAR; 1060 mm TO STARBOARD	2.1	4.2
9BE	MAIN SPAR; 1060 mm TO PORT	3.9	4.7
6BE	MAIN SPAR; 1820 mm TO STARBOARD	-2.1	-0.4
5BE	MAIN SPAR; 1820 mm TO PORT	5.2	6.5
2BE	MAIN SPAR; 2830 mm TO STARBOARD	-0.5	-0.4

* TO OBTAIN STRAIN DATUMS AT ZERO LOAD (ZERO N), INTERPOLATION WAS PERFORMED ON THE FIRST APPLICABLE DATA.

TABLE 13. WING BENDING CALIBRATION
INTERCEPTS OF REGRESSION LINES ON STRAIN AXIS
TEST DATES: 5 & 13 SEPT. 1979
REAR SPAR GAUGES & SKIN ROSETTE

GAUGE NO.	GAUGE LOCATION; DISTANCE FROM AIRCRAFT CENTRELINE	*INTERCEPTS ON STRAIN AXIS ($X10^{-6}$)	
		TESTS ON 5 SEPT. 1979 (2 RUNS COMBINED)	TESTS ON 13 SEPT. 1979 (2 RUNS COMBINED)
18CE	REAR SPAR; 1060 mm TO STARBOARD	0.9	3.0
20TE	REAR SPAR; 1060 mm TO STARBOARD	0.1	-0.6
8BE	REAR SPAR; 1820 mm TO STARBOARD	-0.6	1.4
4BE	REAR SPAR; 2830 mm TO STARBOARD	0.7	0.5
32RA	SKIN ROSETTE; 630 mm TO STARBOARD	-21.8	-26.2
32RB	SKIN ROSETTE; 630 mm TO STARBOARD	-11.1	-13.2
32RC	SKIN ROSETTE; 630 mm TO STARBOARD	2.2	2.2

* TO OBTAIN STRAIN DATUMS AT ZERO LOAD (ZERO N) INTERPOLATION WAS PERFORMED ON THE FIRST APPLICABLE DATA.

TABLE 14. WING BENDING CALIBRATION
INTERCEPTS OF REGRESSION LINES ON STRAIN AXIS
TEST DATES: 5 & 13 SEPT. 1979
SHEAR GAUGES & ROOT RIB GAUGES

GAUGE NO.	GAUGE LOCATION; DISTANCE AFT OF FUSELAGE DATUM <u>OR</u> SPANWISE	*INTERCEPTS ON STRAIN AXIS ($X10^{-6}$)	
		TEST ON 5 SEPT. 1979	TEST ON 13 SEPT. 1979
		(2 RUNS COMBINED)	(2 RUNS COMBINED)
21SE	WING FRONT SPAR SHEAR; 660 mm TO PORT SIDE	-0.8	0.3
22SE	WING FRONT SPAR SHEAR; 660 mm TO STARBOARD SIDE	-4.7	-5.7
26SE	WING ROOT RIB SHEAR; 1800 mm AFT OF FUSE. DATUM, STBD. SIDE	2.3	5.1
30SE	WING ROOT RIB SHEAR; 2840 mm AFT OF FUSE. DATUM, STBD. SIDE	-4.5	-3.7
24SE	WING REAR SPAR SHEAR; 610 mm TO STARBOARD	2.6	2.4
27SE	PORT ROOT RIB BENDING; 2360 mm AFT OF FUSE. DATUM	-6.2	-13.0
28SE	STBD. ROOT RIB BENDING; 2360 mm AFT OF FUSE. DATUM	-8.6	-12.2

* TO OBTAIN STRAIN DATUMS AT ZERO LOAD (ZERO N) INTERPOLATION WAS PERFORMED ON THE FIRST APPLICABLE DATA.

TABLE 15. TAILPLANE CALIBRATION LOADING
INTERCEPTS OF REGRESSION LINES ON STRAIN AXIS
TEST DATE: 10 SEPT. 1979

GAUGE NO.	GAUGE LOCATION; DISTANCE AFT OF FUSELAGE DATUM, OR SPANWISE FROM AIRCRAFT CENTRELINE	INTERCEPTS ON STRAIN AXIS ($X10^{-6}$)		
		DOWN LOADING TWO RUNS COMBINED	UP LOADING TWO RUNS COMBINED	ALL UP & DOWN LOADINGS COMBINED
36BE	TAILPLANE SPAR 900 mm TO STARBOARD	7.7	-9.6	-9.6
37BE	TAILPLANE SPAR 190 mm TO PORT	8.8	-13.0	2.3
38BE	TAILPLANE SPAR 190 mm TO STBD	-4.3	-8.0	1.4
51CE	FUSELAGE LOWER PORT, 3110 mm AFT	-1.5	2.2	-.9
52CE	FUSELAGE LOWER STBD, 3110 mm AFT	-1.0	1.3	-.7
53TE	FUSELAGE UPPER PORT, 3330 mm AFT	1.3	-1.3	0.0
54TE	FUSELAGE UPPER STBD, 3330 mm AFT	0.7	-.5	-.2

NOTES: 1. ALL INTERCEPTS ARE RELATIVE TO THE MEAN OF THE VALUES AT THE START OF FOUR LOADINGS (INCLUDING UP & DOWN LOADINGS)

2. DOWN LOADING (-VE) PRECEDED UPWARDS LOADING.

TABLE 16. FIN CALIBRATION LOADING
INTERCEPTS OF REGRESSION LINES ON STRAIN AXIS
TEST DATE: 10 SEPT. 1979

GAUGE NO.	GAUGE LOCATION; DISTANCE ABOVE FUSELAGE REF. LINE (FRL) OR DISTANCE AFT OF FUSELAGE DATUM (FD)	INTERCEPTS ON STRAIN AXIS ($X10^{-6}$)		
		LOADING TO STBD. TWO RUNS COMBINED	LOADING TO PORT TWO RUNS COMBINED	ALL STBD & PORT LOADINGS COMBINED
33TE	FIN SPAR, PORT SIDE, 190 mm ABOVE F.R.L.	13.9	-14.7	-5.3
34TE	FIN SPAR, STBD SIDE 190 mm ABOVE F.R.L.	-24.5	25.5	-0.7
51CE	FUSELAGE LOWER PORT, 3110 mm AFT OF F.D.	-0.5	0.1	0.0
52CE	FUSELAGE LOWER STBD, 3110 mm AFT OF F.D.	0.1	-0.3	0.2
53TE	FUSELAGE UPPER PORT, 3330 mm AFT OF F.D.	0.4	-0.6	-0.3
54TE	FUSELAGE UPPER STBD, 3330 mm AFT OF F.D.	-0.4	0.5	-0.2

NOTES: 1. STARBOARD LOADINGS (+VE) PRECEDED PORT LOADINGS.
2. ALL INTERCEPTS ARE RELATIVE TO THE MEAN OF THE VALUES AT THE START OF FOUR LOADINGS (INCLUDING STARBOARD & PORT DIRECTIONS).

TABLE 17. COMPARISON OF WING BENDING CALIBRATIONS
STRAIN/LOAD GRADIENTS
TEST DATES: MARCH 1977, SEPT. 1979
MAIN SPAR GAUGES

GAUGE NO.	GAUGE LOCATION; DISTANCE FROM AIRCRAFT CENTRELINE	SLOPE STRAIN ($X10^{-6}$) PER LOAD (N) PER SIDE		CHANGE (PERCENT)	CHANGE (MICROSTRAIN)
		TESTS MARCH 1977	TESTS SEPT. 1979		
12BE	MAIN SPAR; 360 mm TO STARBOARD	0.1023	0.0876	-14.5	-180
10BE	MAIN SPAR; 1060 mm TO STARBOARD	0.0724	0.0742	+2.4	21
9BE	MAIN SPAR; 1060 mm TO PORT	0.0740	0.0754	+1.9	17
6BE	MAIN SPAR; 1820 mm TO STARBOARD	0.0616	0.0608	-1.3	-9
5BE	MAIN SPAR; 1820 mm TO PORT	0.0628	0.0628	0.0	0
2BE	MAIN SPAR; 2830 mm TO STARBOARD	0.0239	0.0228	-4.7	-13

TABLE 18. COMPARISON OF WING BENDING CALIBRATIONS
STRAIN/LOAD GRADIENTS
TEST DATES: MARCH 1977, SEPT. 1979
REAR SPAR GAUGES & SKIN ROSETTE

GAUGE NO.	GAUGE LOCATION; DISTANCE FROM AIRCRAFT CENTRELINE	SLOPE: STRAIN ($X10^{-6}$) PER LOAD (N) PER SIDE		CHANGE (PERCENT)	CHANGE (MICROSTRAIN)
		TESTS MARCH1977	TESTS SEPT. 1979		
18CE	REAR SPAR, 1060 mm TO STARBOARD	-0.0052	-0.0031	-41.2	-24
20TE	REAR SPAR; 1060 mm TO STARBOARD	0.0344	0.0348	+1.2	5
8BE	REAR SPAR; 1820 mm TO STARBOARD	0.0420	0.0418	-0.5	-2
4BE	REAR SPAR; 2830 mm TO STARBOARD	0.0203	0.0204	+0.5	1
32RA	SKIN ROSETTE; 630 mm TO STARBOARD	0.0270	0.0243	-10.2	-32
32RB	SKIN ROSETTE; 630 mm TO STARBOARD	0.0299	0.0302	+1.0	4
32RC	SKIN ROSETTE; 630 mm TO STARBOARD	-0.0286	-0.0288	+0.7	2

TABLE 19. COMPARISON OF WING BENDING CALIBRATIONS
STRAIN/LOAD GRADIENTS
TEST DATES: MARCH 1977, SEPT. 1979
SHEAR GAUGES & ROOT RIB GAUGES

GAUGE NO.	GAUGE LOCATION; DISTANCE AFT OF FUSELAGE DATUM OR SPANWISE FROM AIRCRAFT CENTRELINE	SLOPE: STRAIN ($X10^{-6}$) PER LOAD (N) PER SIDE		CHANGE (PERCENT)	CHAN[illegible] (MICRO[illegible]
		TESTS MARCH 1977	TESTS SEPT. 1979		
21SE	WING FRONT SPAR SHEAR; 660 mm TO PORT SIDE	-0.0110	-0.0103	-6.5	-8
22SE	WING FRONT SPAR SHEAR; 660 mm TO STBD. SIDE	-0.0202	-0.0204	+1.0	0
26SE	WING ROOT RIB SHEAR; 1800 mm AFT OF FUSE DATUM, STBD. SIDE	-0.0221	-0.0336	+4.4	18
30SE	WING ROOT RIB SHEAR; 2840 mm AFT OF FUSE DATUM, STBD. SIDE	-0.0266	-0.0287	+7.7	24
24SE	WING REAR SPAR SHEAR; 610 mm TO STARBOARD SIDE	-0.0100	-0.0115	+15.3	18
27BE	PORT ROOT RIB BENDING; 2360 mm AFT OF FUSELAGE DATUM	-0.0259	-0.0237	-8.7	24
28BE	STBD. ROOT RIB BENDING; 2360 mm AFT OF FUSELAGE DATUM	-0.0310	-0.0288	-7.2	24

TABLE 20. COMPARISON OF TAILPLANE CALIBRATIONS
STRAIN/LOAD GRADIENTS
TEST DATES: MARCH 1977, SEPT. 1979

GAUGE NO.	GAUGE LOCATION; DISTANCE FROM AIRCRAFT CENTRELINE <u>OR</u> AFT OF FUSE. DATUM	SLOPE: STRAIN ($x10^{-6}$) PER LOAD (N) PER SIDE		CHANGE (PERCENT)	CHANGE (MICROSTRAIN)
		TESTS MARCH 1977	TESTS SEPT. 1979		
36BE	TAILPLANE SPAR 900 mm TO STARBOARD	0.459	0.469	+2.2	11
37BE	TAILPLANE SPAR 200 mm TO PORT	0.731	0.664	-9.1	-75
38BE	TAILPLANE SPAR 200 mm TO STBD.	0.766	0.708	-7.6	-64
51CE	FUSELAGE LOWER PORT, 3110 mm AFT	0.097	0.089	-8.4	9
52CE	FUSELAGE LOWER STBD., 3110 mm AFT	0.106	0.108	+1.9	2
53TE	FUSELAGE UPPER PORT, 3330 mm AFT	-0.153	-0.157	+2.7	4
54TE	FUSELAGE UPPER STBD., 3330 mm AFT	-0.164	-0.144	-12.4	-22

TABLE 21. COMPARISON OF FIN CALIBRATIONS
STRAIN/LOAD GRADIENTS
TEST DATES: MARCH 1977; SEPT. 1979

GAUGE NO.	GAUGE LOCATION; DISTANCE ABOVE FUSE. REF. LINE (F.R.L.) OR DISTANCE AFT OF FUSELAGE DATUM	SLOPE, STRAIN ($X10^{-6}$) PER LOAD (N) PER SIDE		CHANGE (PERCENT)	CHANGE (MICROSTRAIN)
		TESTS MARCH 1977	TESTS SEPT. 1979		
33TE	FIN SPAR, PORT SIDE 190 mm ABOVE F.R.L.	0.828	0.787	-4.9	-36
34TE	FIN SPAR, STBD. SIDE 190 mm ABOVE F.R.L.	-0.855	-0.820	-4.0	-35
51CE	FUSELAGE LOWER PORT, 3110 mm AFT	0.037	0.040	+8.3	3
52CE	FUSELAGE LOWER STBD, 3110 mm AFT	-0.037	-0.048	+30.6	10
53TE	FUSELAGE UPPER PORT, 3330 mm AFT	-0.026	0.018	169	39
54TE	FUSELAGE UPPER STBD, 3330 mm AFT	0.021	-0.021	-200	-37

Notes:

BE:–	Bending bridge, combining tensile & compressive strains.
CE, TE:–	Separate compressive or tensile strains.
SE:–	Shear bridge
RA, RB, RC:–	Rosette

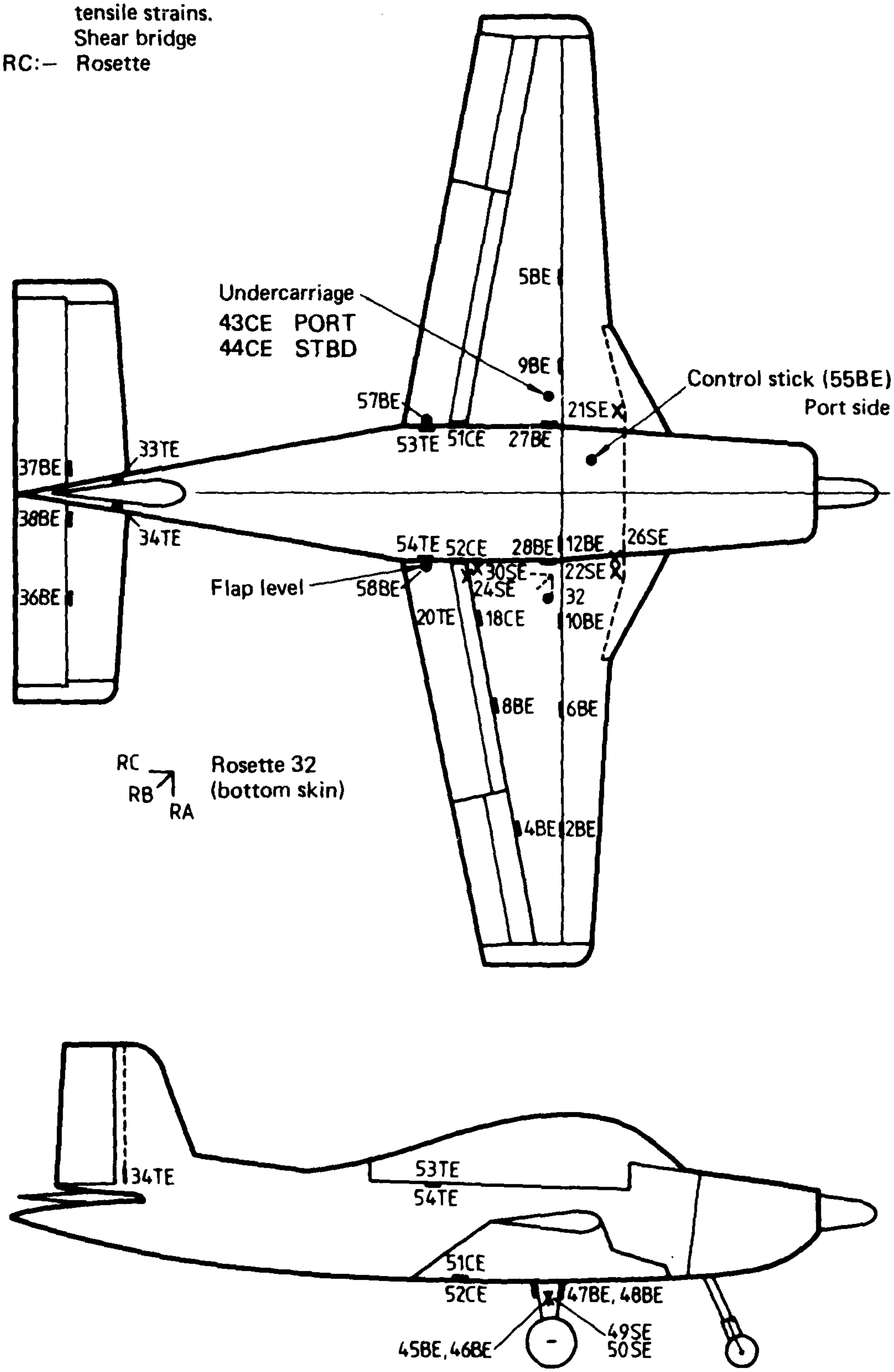

FIG. 1 CT–4A AIRTRAINER – STRAIN GAUGE POSITIONS ON FLIGHT TEST AIRCRAFT

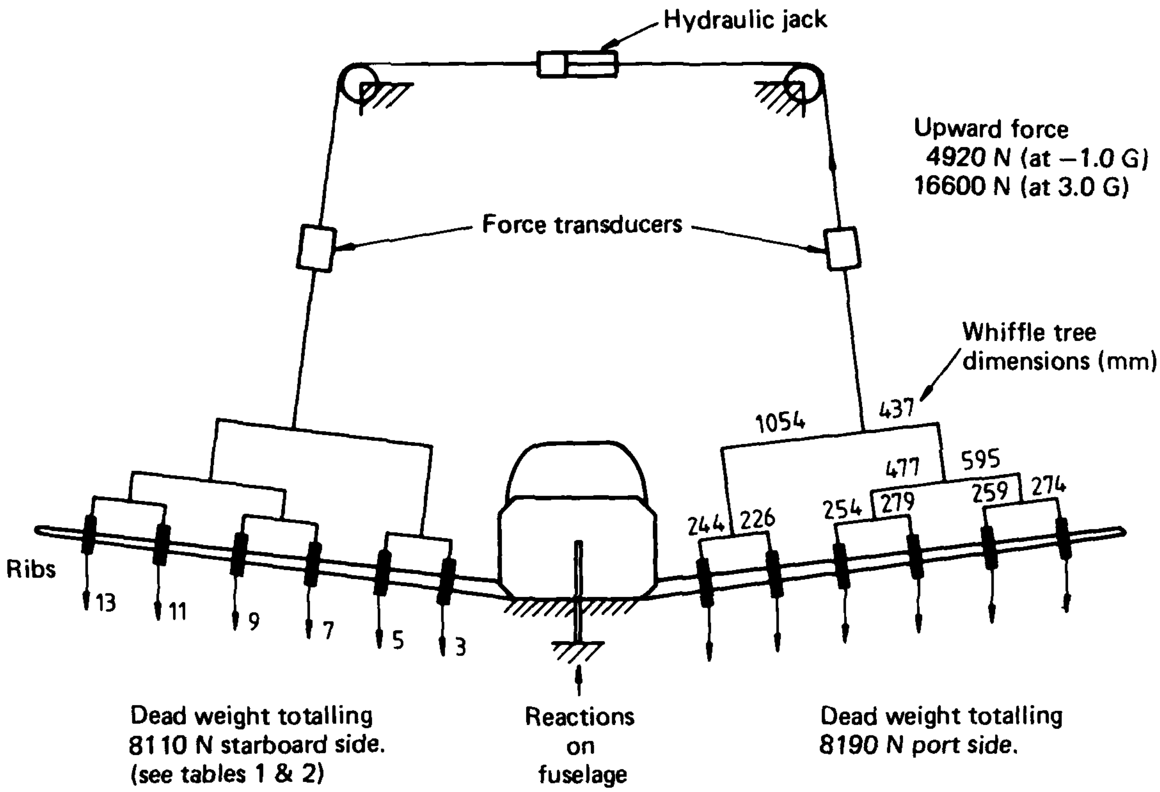

FIG. 2 LOADING SCHEME – CT–4A WING BENDING CALIBRATION

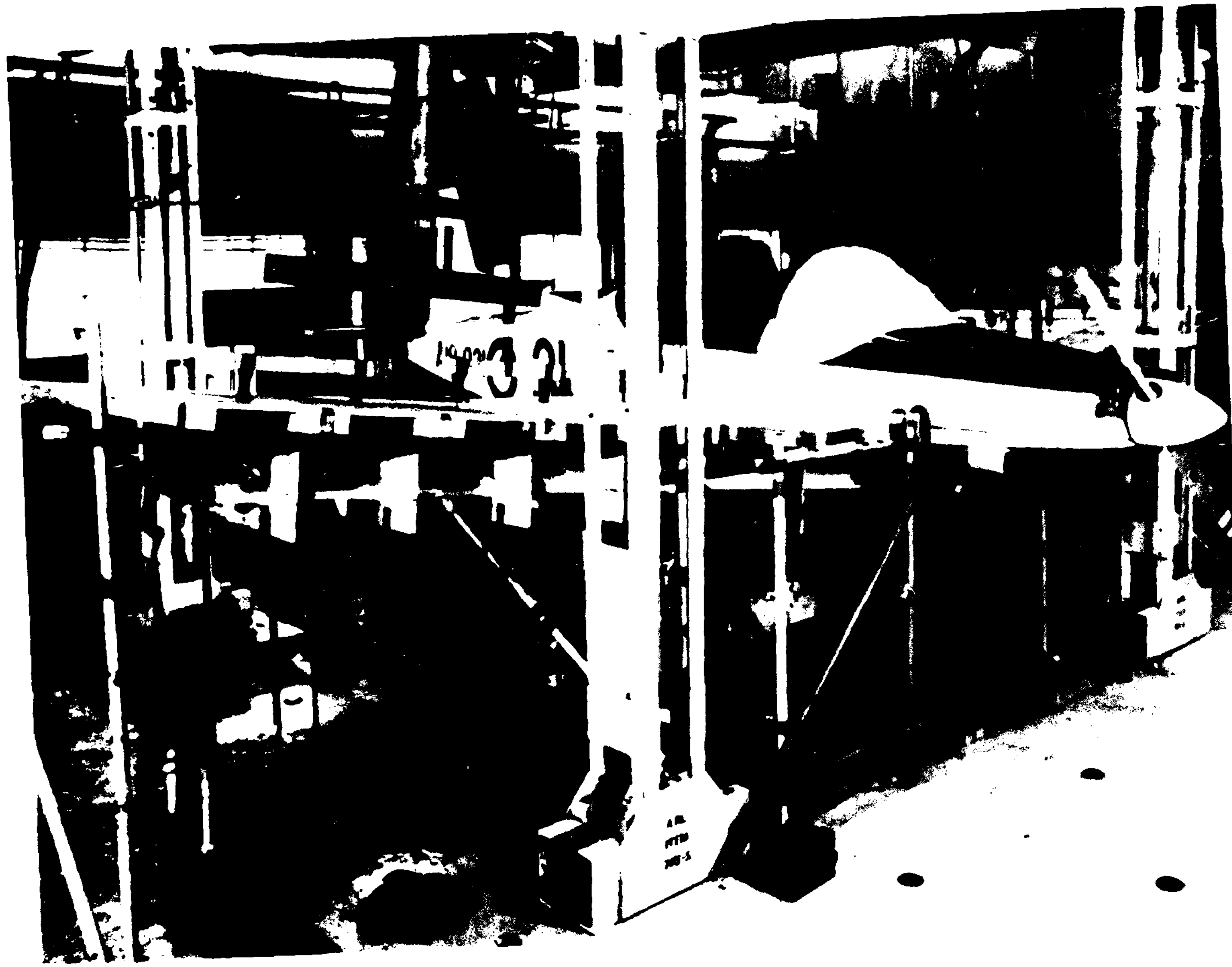

FIG. 3 CT–4A WING BENDING CALIBRATION (1977)

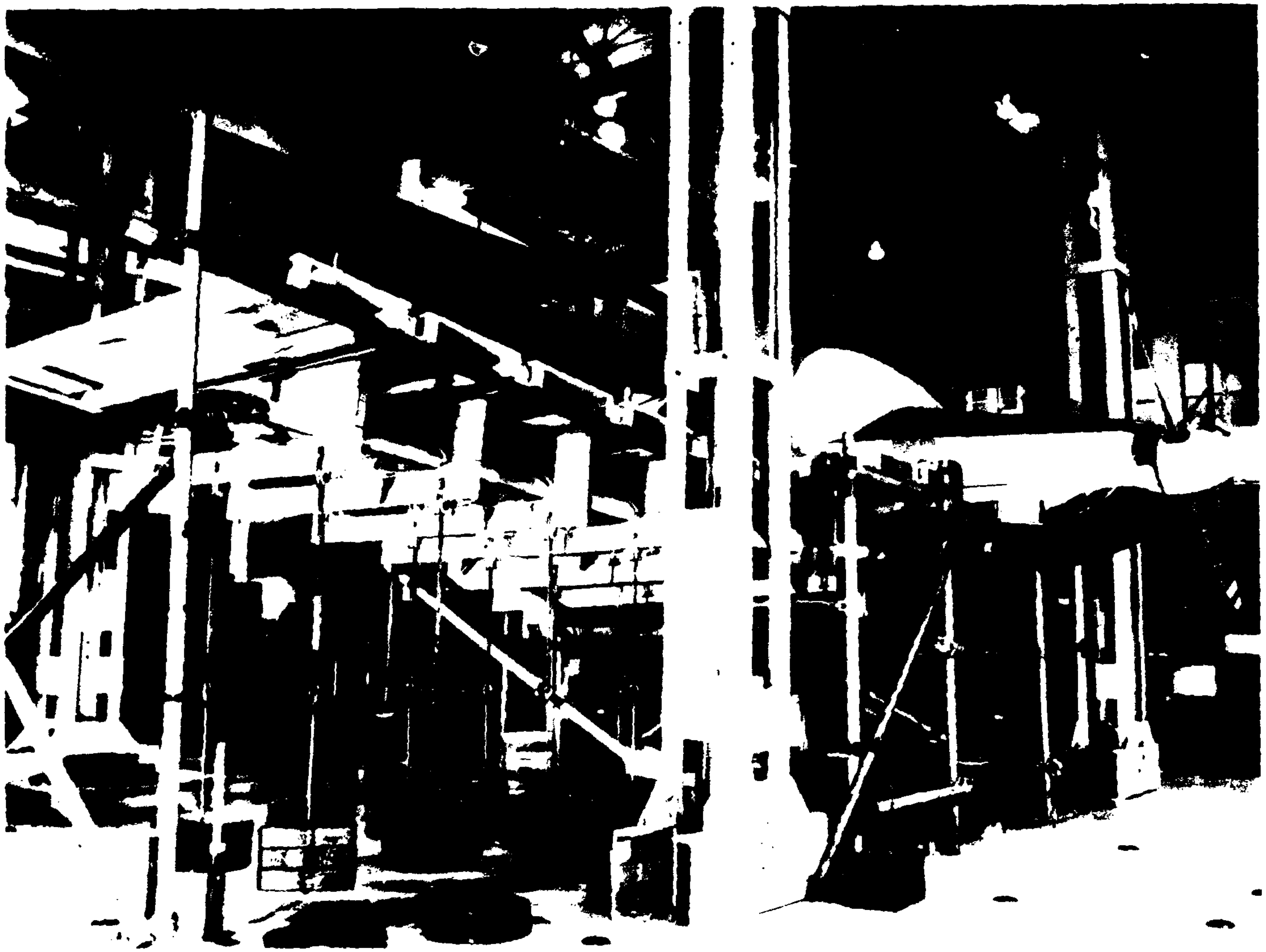

FIG. 4 CT–4A WING BENDING CALIBRATION (1977)

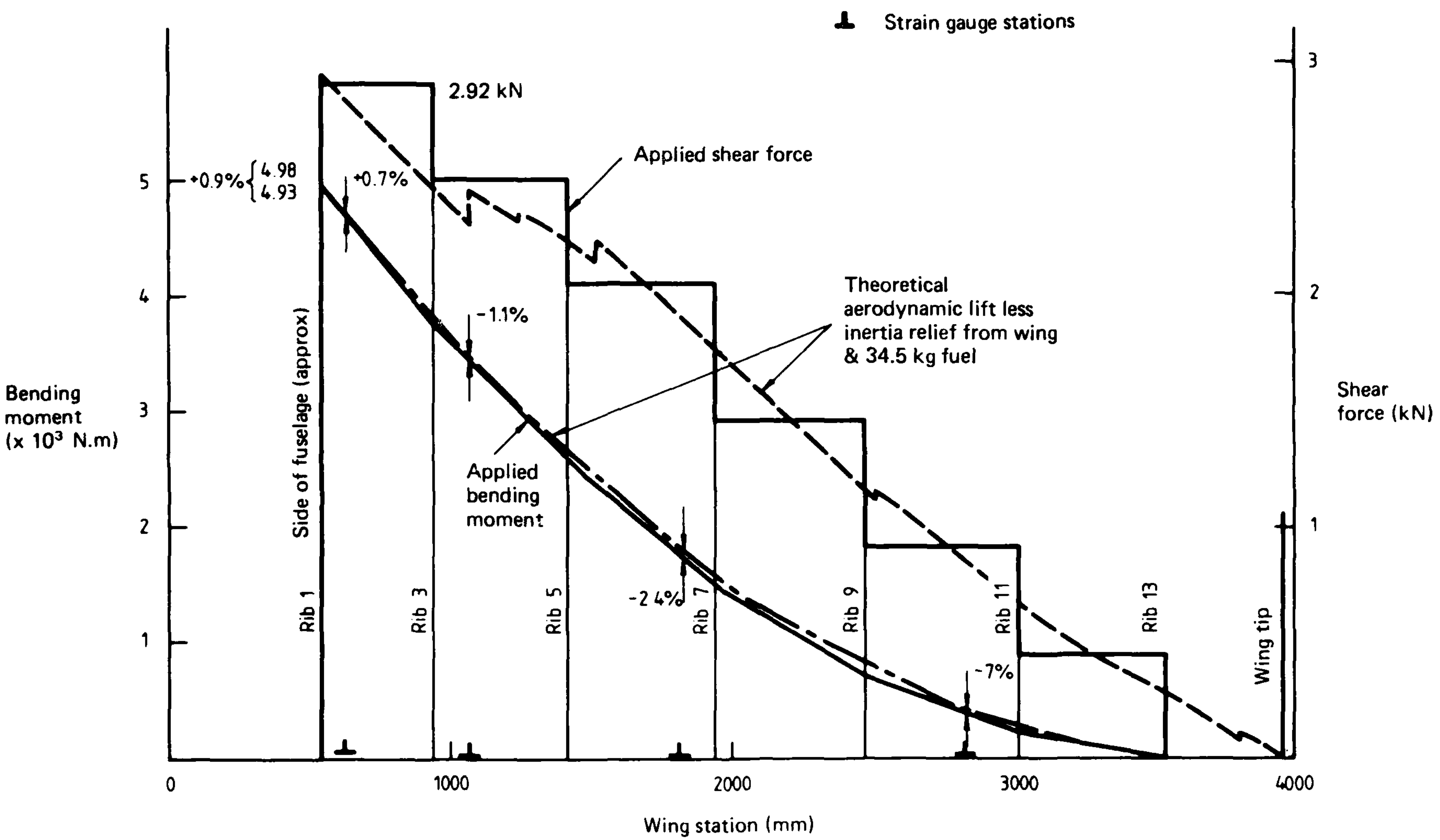

FIG. 5 THEORETICAL AND APPLIED SHEAR FORCE & BENDING MOMENT DIAGRAMS FOR 1–g LOAD INCREMENT – WING BENDING CASE

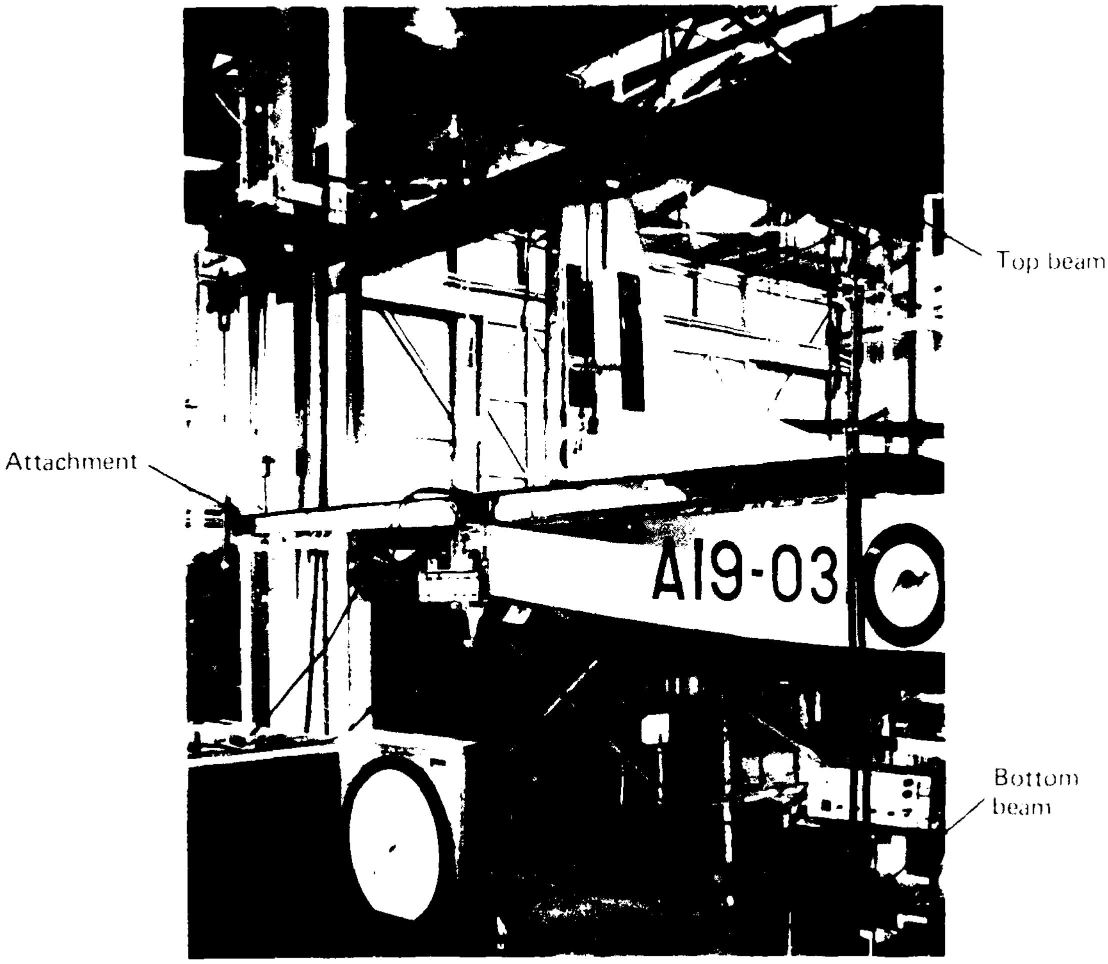

FIG. 6 CT-4A TAILPLANE CALIBRATION (1977)

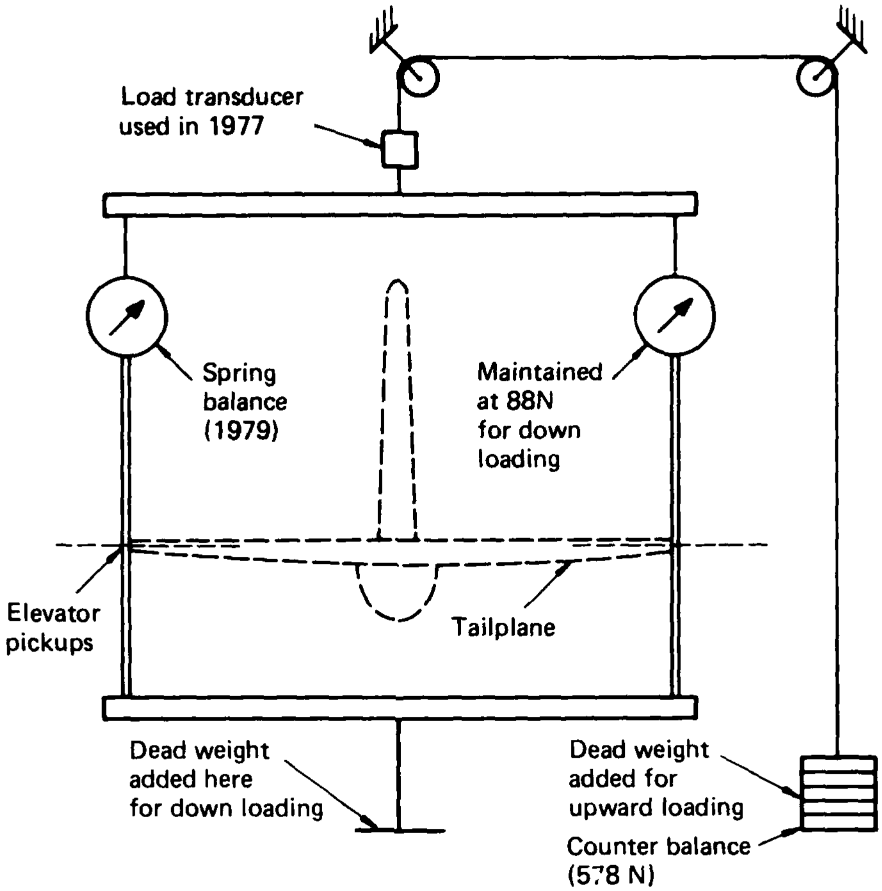

FIG. 7 CT—4A TAILPLANE CALIBRATION LOADING

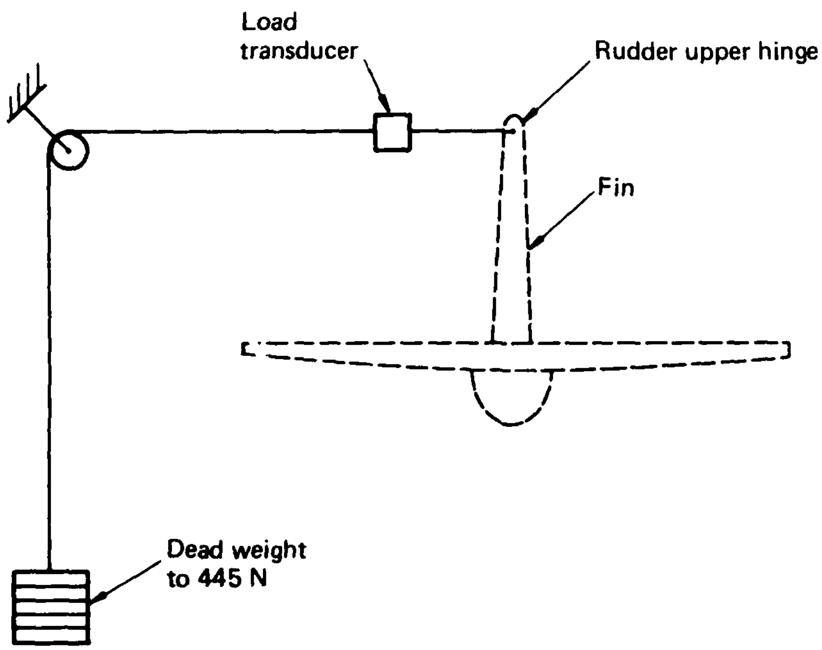

FIG. 8 CT—4A FIN CALIBRATION LOADING AS FOR PORT SIDE

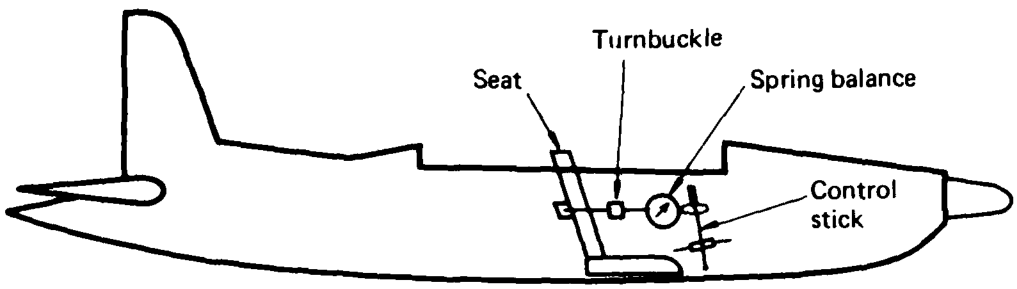

FIG. 9 CT–4A CONTROL STICK – CALIBRATION

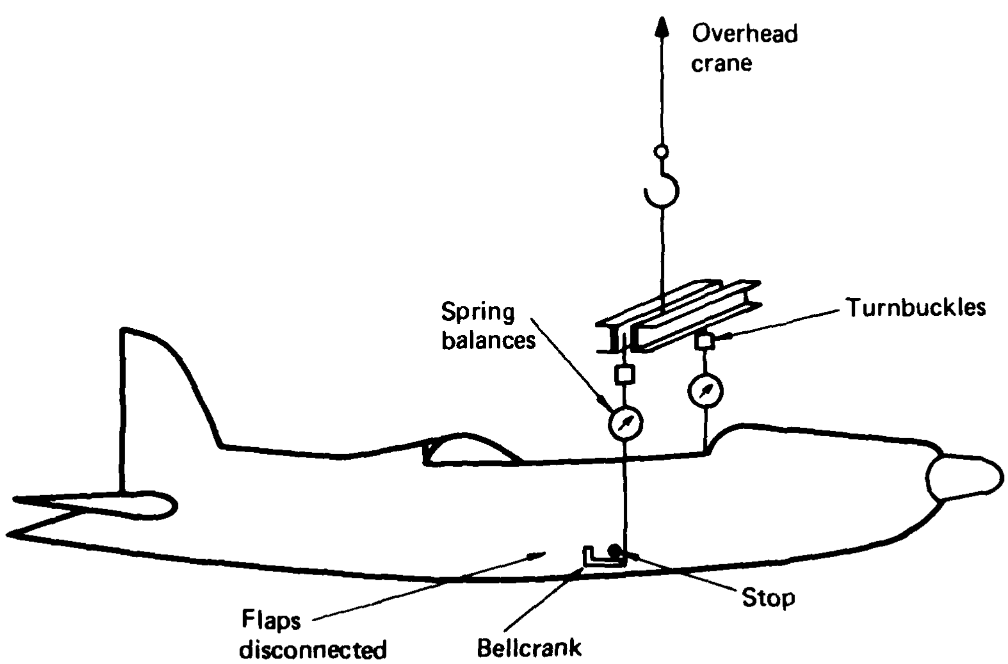

FIG. 10 CT–4A FLAP BELLCRANK LEVERS – CALIBRATION

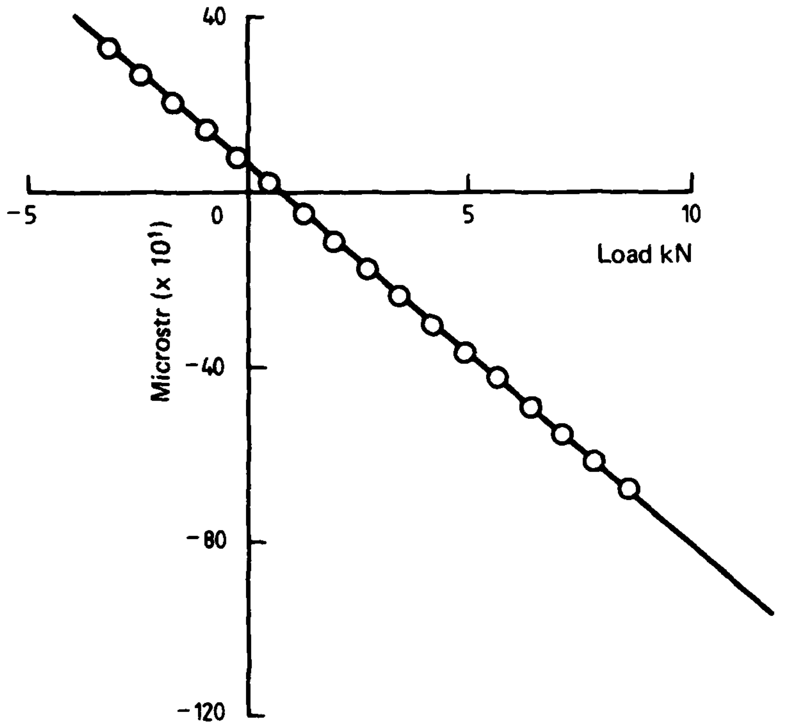

FIG. 11 STRAIN GAUGE 12 BE (MAIN SPAR CENTRE SECTION) STRAIN READING/LOAD PLOT. WING BENDING CALIBRATION. NEGATIVE SLOPE IS APPARENTLY CAUSED BY A WIRING CHANGE.

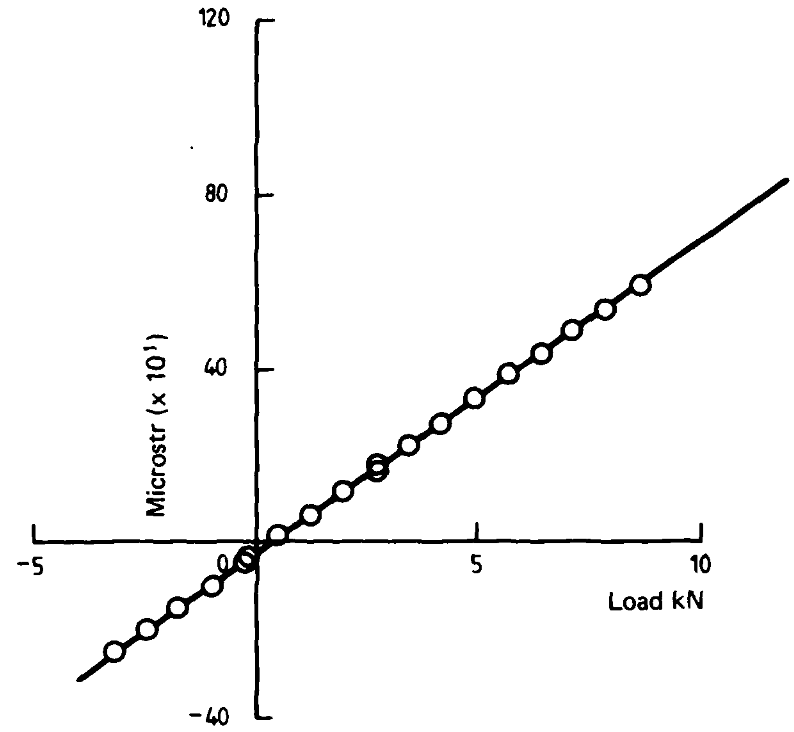

FIG. 12 STRAIN GAUGE 10 BE (WING MAIN SPAR) STRAIN READING/LOAD PLOT. WING BENDING CALIBRATION.

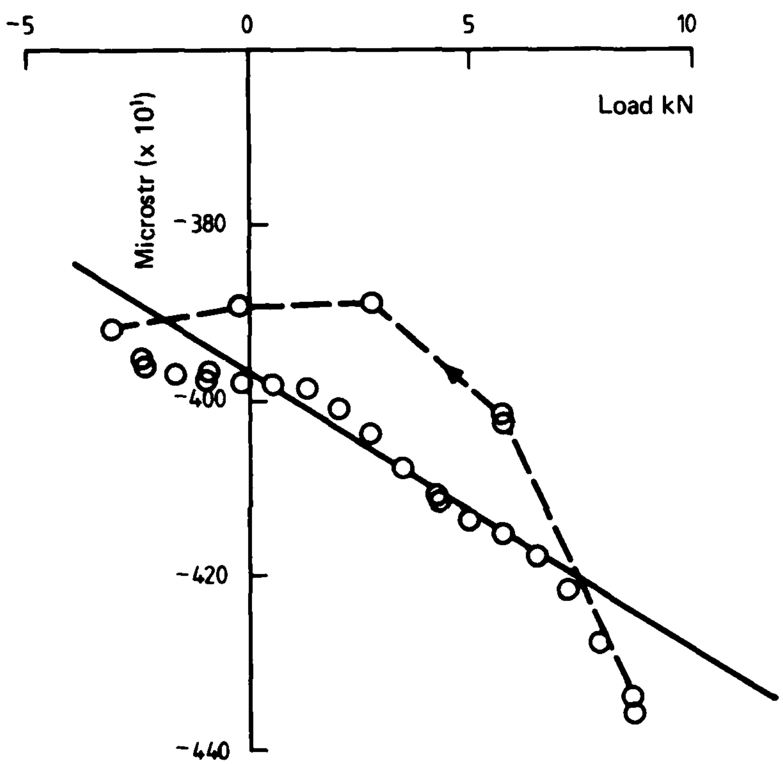

FIG. 13 STRAIN GAUGE 18 CE (REAR SPAR BOOM) STRAIN READING/LOAD PLOT. WING BENDING CALIBRATION

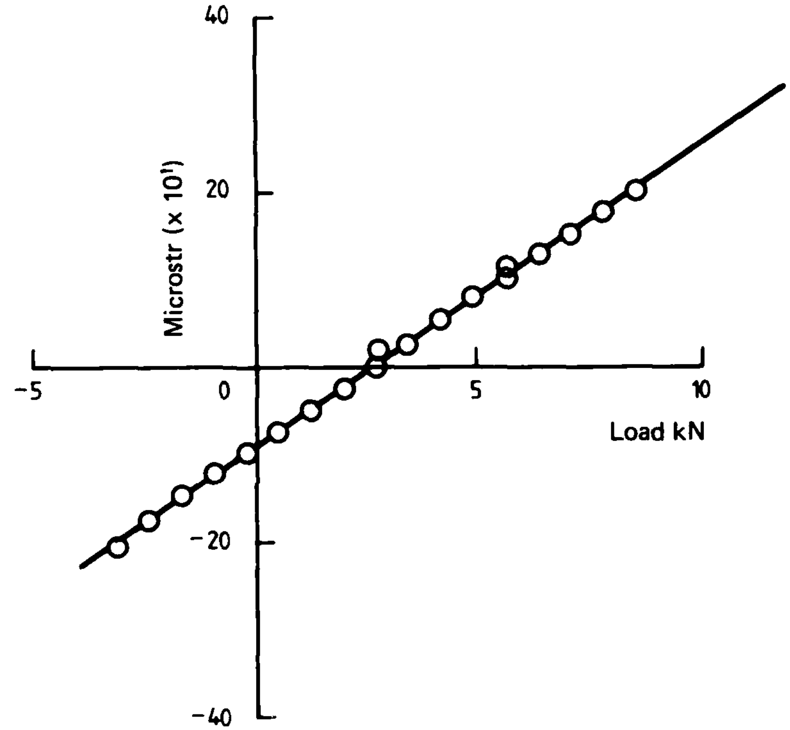

FIG. 14 STRAIN GAUGE 20 TE (REAR SPAR BOOM) STRAIN READING/ LOAD PLOT. WING BENDING CALIBRATION

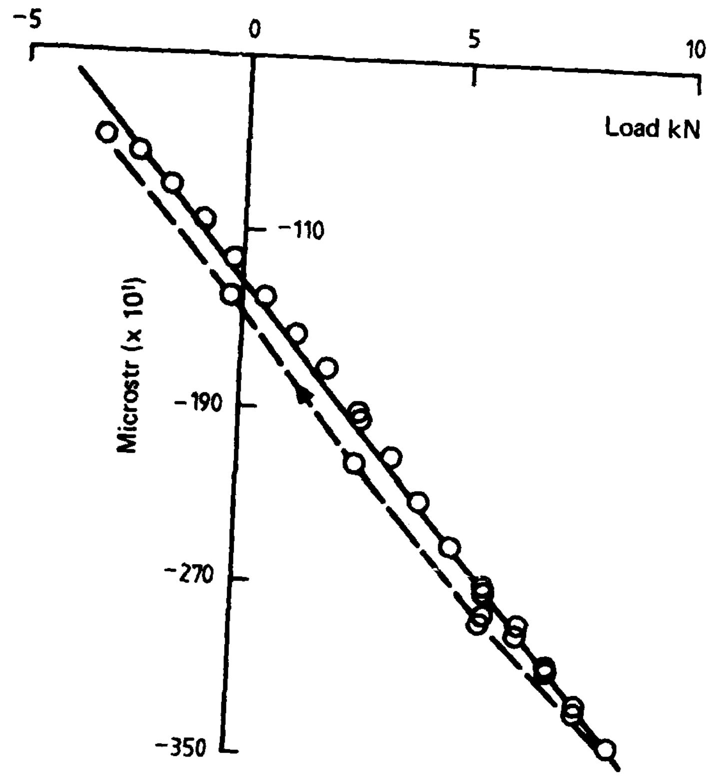

FIG. 15 STRAIN GAUGE 27 BE (WING ROOT RIB BENDING) STRAIN READING/LOAD PLOT. WING BENDING CALIBRATION

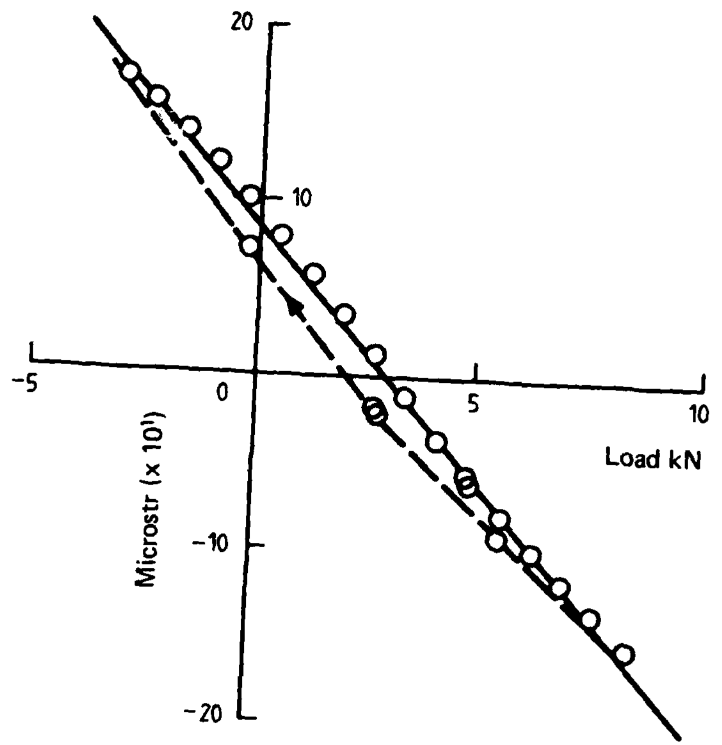

FIG. 16 STRAIN GAUGE 28 BE (WING ROOT RIB BENDING) STRAIN READING/LOAD PLOT. WING BENDING CALIBRATION.

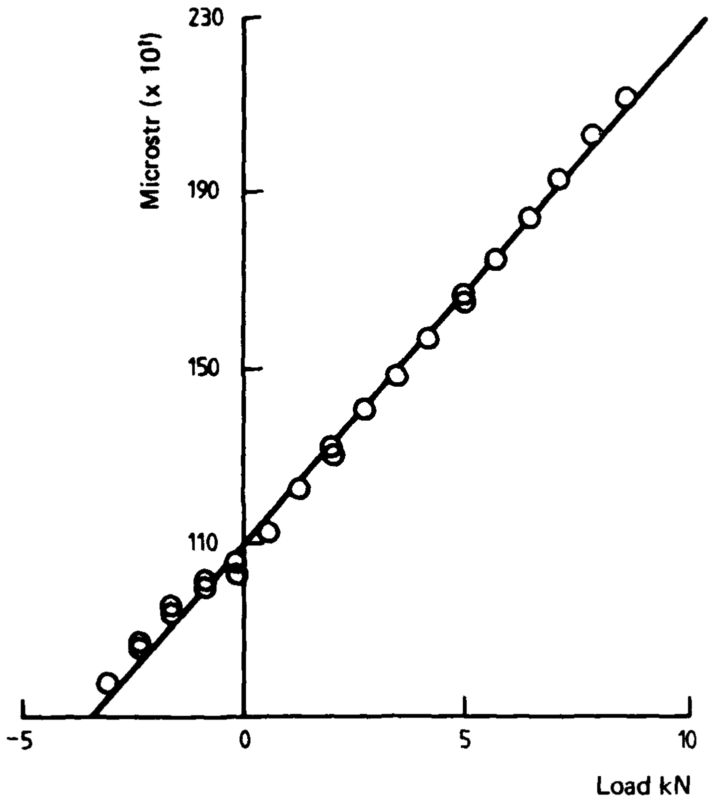

FIG. 17 STRAIN GAUGE 24 SE (REAR SPAR SHEAR NEAR PICKUP) STRAIN READING/ LOAD PLOT. WING BENDING CALIBRATION.

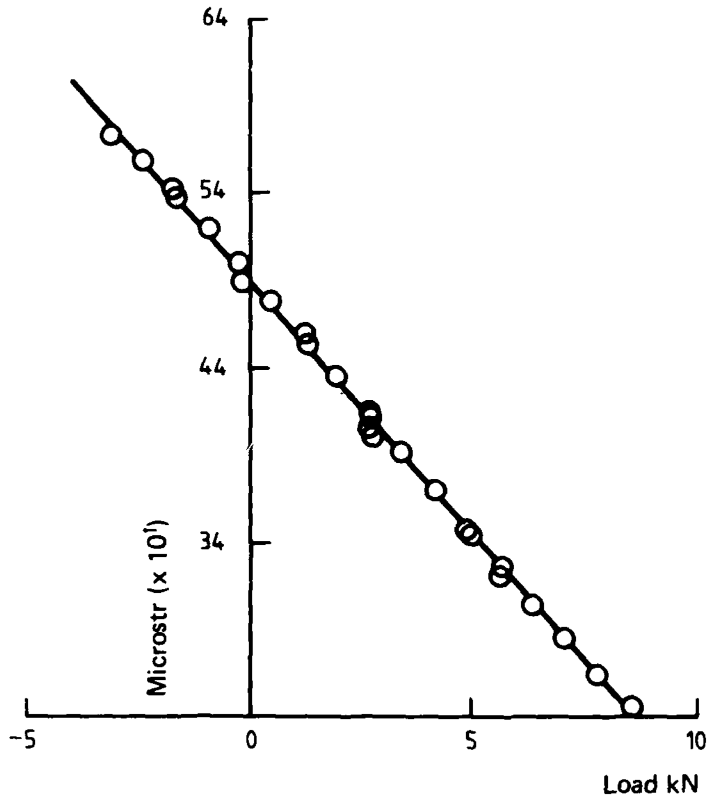

FIG. 18 STRAIN GAUGE 30 SE (SHEAR NEAR REAR SPAR PICKUP) STRAIN READING/LOAD PLOT. WING BENDING CALIBRATION.

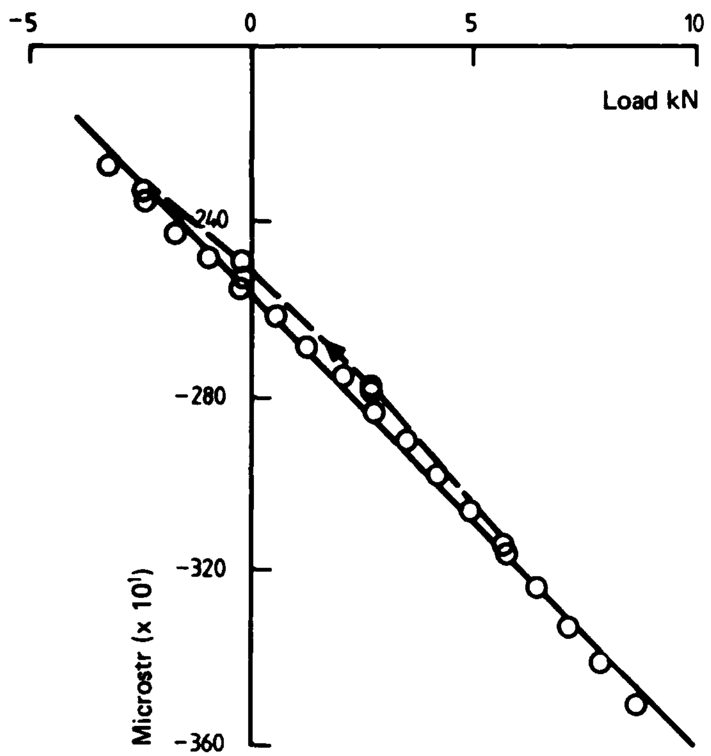

FIG. 19 STRAIN GAUGE 21 SE (SHEAR NEAR PORT FRONT SPAR PICKUP) – STRAIN READING/LOAD PLOT FOR WING BENDING CALIBRATION.

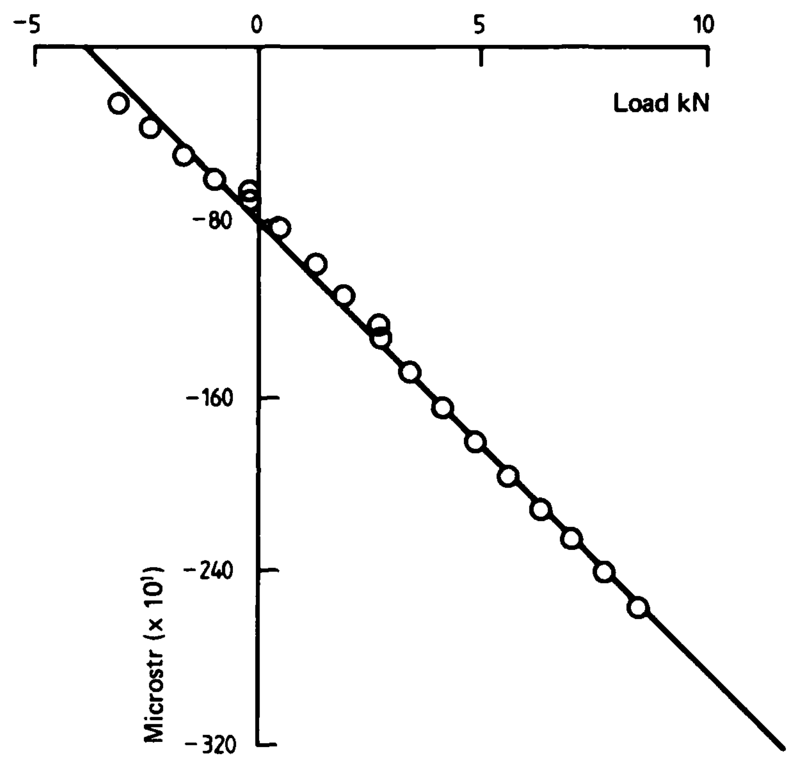

FIG. 20 STRAIN GAUGE 22 SE (SHEAR NEAR STARBOARD FRONT SPAR PICKUP) – STRAIN READING/LOAD PLOT FOR WING BENDING CALIBRATION.

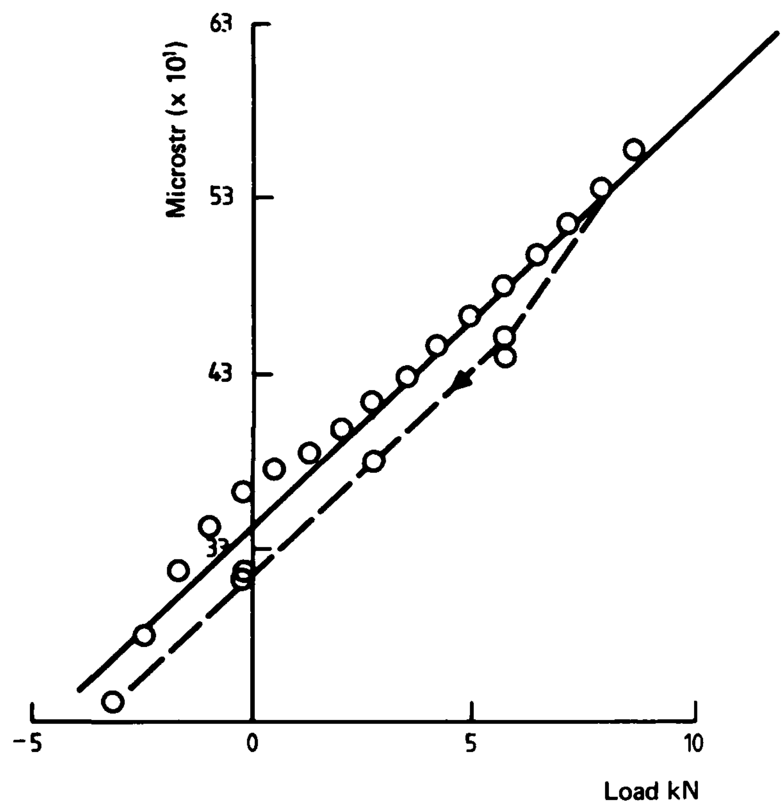

FIG 21 STRAIN GAUGE 32 RA (WING SKIN ROSETTE – SPANWISE ARM). STRAIN READING/LOAD PLOT. WING BENDING CALIBRATION.

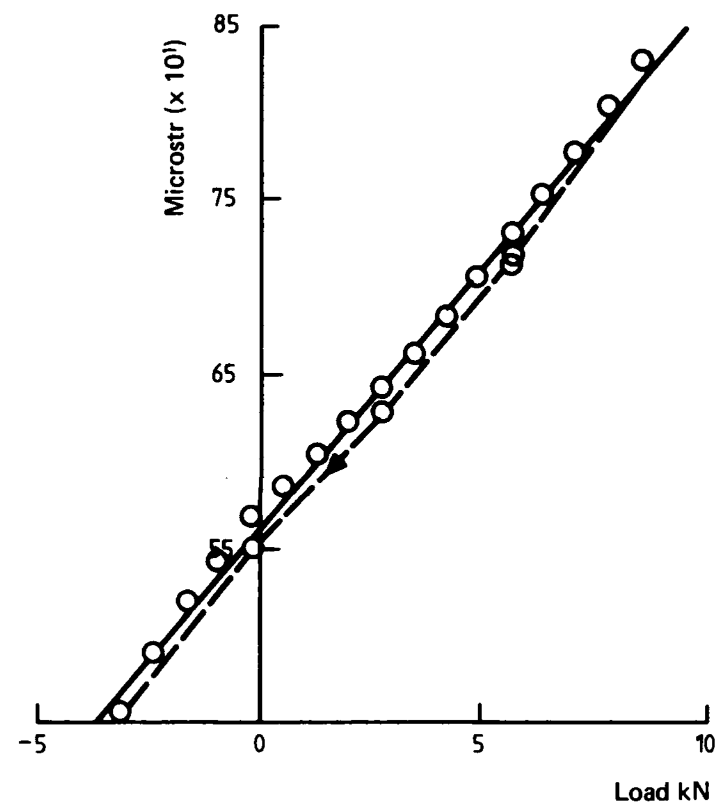

FIG. 22 STRAIN GAUGE 32 RB (WING SKIN ROSETTE – DIAGONAL ARM). STRAIN READING/LOAD PLOT. WING BENDING CALIBRATION.

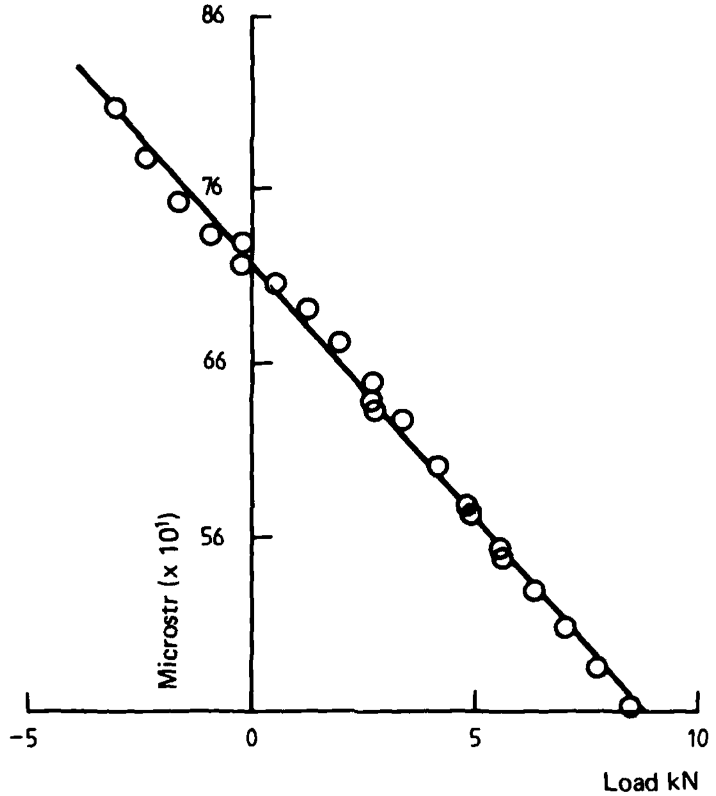

FIG. 23 STRAIN GAUGE 32 RC (WING SKIN ROSETTE – ARM PERPENDICULAR TO SPAR) STRAIN READING/LOAD PLOT FOR WING BENDING CALIBRATION.

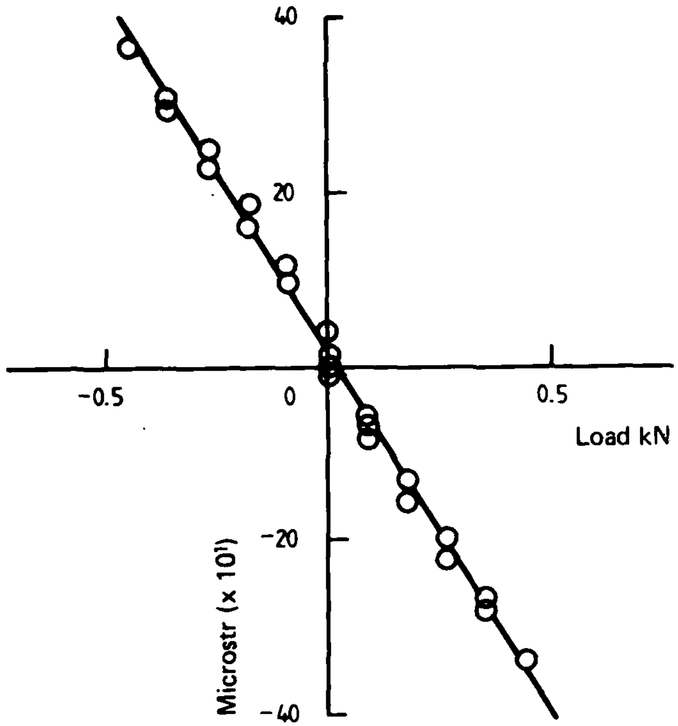

FIG. 24 FIN STRAIN GAUGE, 34 TE.
STRAIN/LOAD PLOT FOR FIN
CALIBRATION.

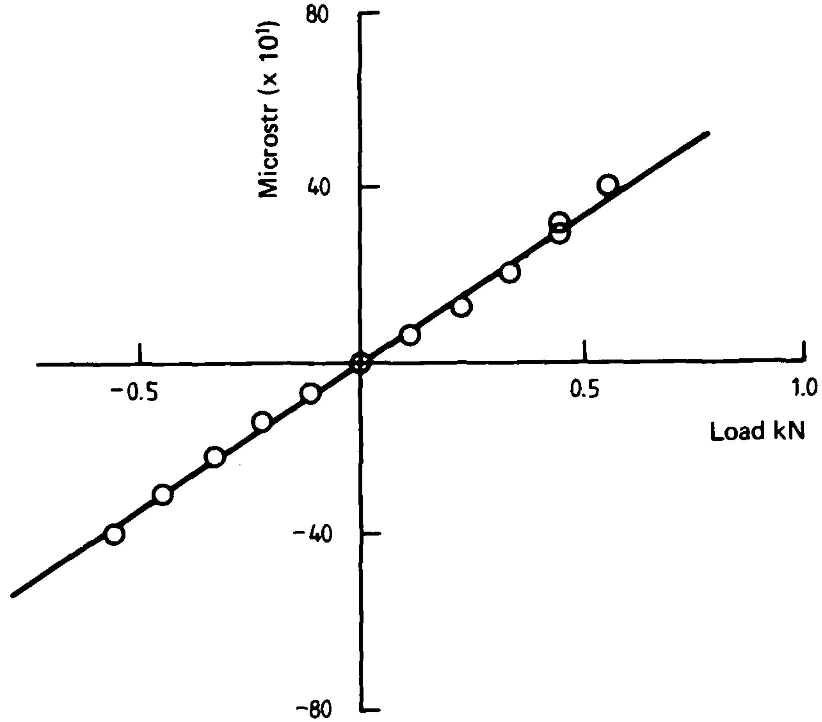

FIG. 25 TAILPLANE BENDING
STRAIN GAUGE, 37 BE. STRAIN/
LOAD PLOT FOR TAILPLANE CALIBRATION.

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